

# METEOROLOGICAL AND REMOTE SENSING APPLICATIONS OF HIGH ALTITUDE UNMANNED AERIAL VEHICLES\*

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## ABSTRACT

Unmanned aerial vehicles (UAVs) are maturing in performance and becoming available for routine use in environmental applications including weather reconnaissance and remote sensing. This paper presents a discussion of UAV characteristics and unique features compared with other measurement platforms. A summary of potential remote sensing applications is provided, along with details for four types of tropical cyclone missions. Capabilities of platforms developed under NASA's Environmental Research Aircraft and Sensor Technology (ERAST) program are reviewed, including the Altus, Perseus, and solar-powered Pathfinder, all of which have flown to over 57,000 ft (17 km). In many scientific missions, the science objectives drive the experimental design, thus defining the sensor payload, aircraft performance, and operational requirements. Some examples of science missions and the requisite UAV / payload system are given. A discussion of technology developments needed to fully mature UAV systems for routine operational use is included, along with remarks on future science and commercial UAV business opportunities.

## 1.0 INTRODUCTION

A new class of unmanned aerial vehicles (UAVs) capable of flying at altitudes above 17 km and is becoming available for scientific and commercial use. They can carry a suite of sensors that can perform remote sensing and collect meteorological data in remote areas of the Earth. These aircraft are seen as a complement to existing manned aircraft and satellites now used for similar purposes. They place no human crew at risk and will ultimately be less expensive to operate compared to traditional manned aircraft. The National Aeronautics and Space Administration (NASA) Environmental Research Aircraft and Sensor Technology (ERAST) program is sponsoring development of several aircraft which could be used in airborne missions to remotely collect data or to demonstrate how meteorological data can be collected and delivered to improve weather forecasts and improve scientific modeling.

These aircraft are supervised by a human controller on the ground using radio communications. Although there are many kinds of payloads that can be carried by these aircraft, the most common are *in situ* atmospheric or imaging sensors. In data gathering applications, the purpose of a UAV is to carry its sensor payload to a specific place at a specific time. Figure 1 shows the components of a remote sensing system using a UAV. This example is for meteorological monitoring using dropwindsondes (Papadales and Schoenung, 1999) but the major components of any UAV system would be the same: aircraft platform, communications and control system, sensor system, and data acquisition system.

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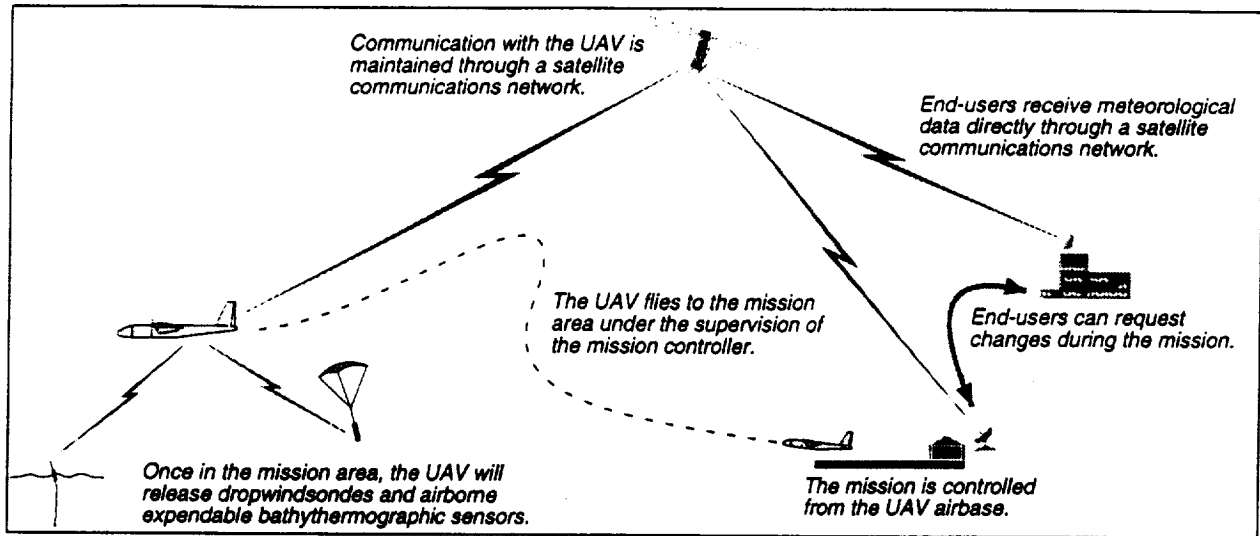


Figure 1. Components of a UAV system for Meteorological Studies.

## 2.0 APPLICATIONS

UAVs have the potential to complement and extend observations of key environmental processes beyond that of satellites and conventional piloted aircraft, providing a unique vantage point to study the earth system.

Generally, the advantages of UAVs have been expressed as:

- Long range capability—can fly to remote places or cover large areas
- Long endurance capability—can fly longer than manned aircraft and revisit frequently
- High altitude capability—can fly above weather, traffic or danger
- Slow speed flight—can loiter at or near one location
- Pilot exposure is eliminated—allows for long duration or dangerous flights

The performance envelope relative to manned aircraft has been shown in various ways; one typical depiction is shown in Figure 2.

Many applications have been suggested. These fall into the categories of:

- 1) Very high altitude, which is useful primarily for *in situ* atmospheric sampling. (Examples would be studies of ozone depletion or other climate change research. (Anderson and Langford, 1991))
- 2) Mid-to-high altitude with relatively long endurance, which is ideal for many types of remote sensing. (These applications are discussed in more detail below.)
- 3) Low altitude, medium endurance, which has been the province of the military and other specialized agencies.
- 4) Small, low altitude UAVs, which are often hand-launched and fill a niche for localized measurements, such as in precision agriculture or utility monitoring.

Many remote sensing interests that can be best addressed using UAVs that fall in the high altitude, long endurance region. Most of these will use an imaging sensor; some will also carry *in situ* measuring instruments.

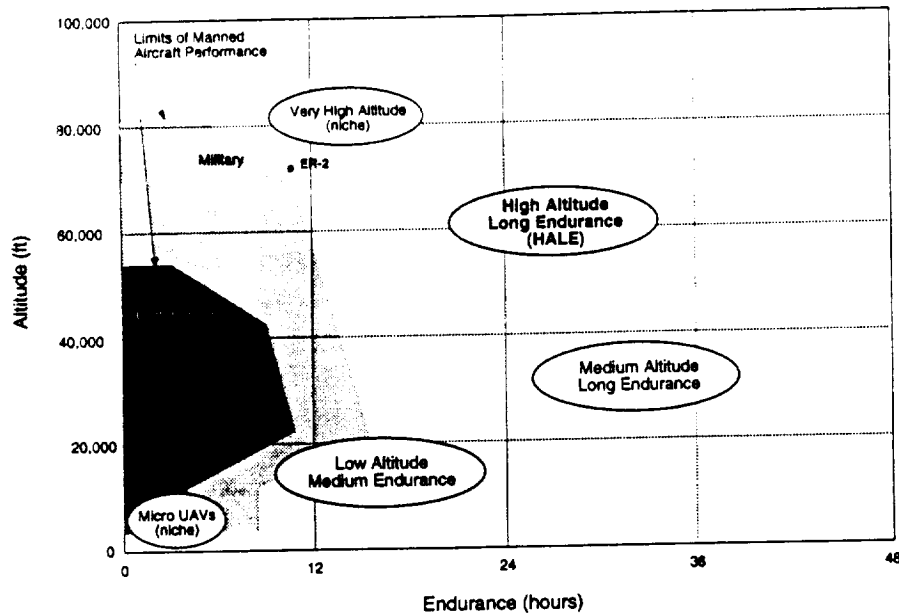


Figure 2. Characteristics of UAVs Compared with Manned Aircraft

Remote sensing missions include:

- Meteorology, especially remote sensing and dropsonde measurements of severe storms and tropical cyclones (This application is described in detail in Section 3.0.)
- Natural hazard and disaster detection, monitoring, and management
- Loitering or frequent revisit, as in traffic monitoring, or other surveillance; or as a telecomm platform
- Mapping, where high altitudes give adequate field of view, or where long range or duration is needed. This can be desirable for land use, land cover, and change detection analysis.
- Remote science (activities needing long range, such as measurements of polar, tropic, or ocean features)
- Diurnal science (> 24 hr data showing changes or cyclic nature of natural or man-made processes, especially thermal signatures)
- Environmental monitoring
  - pollutant plumes (air, water)
  - ocean or coastal monitoring
- Agriculture and forestry management, especially where real-time or near real-time data are needed for daily management activities.
  - Precision farming: optimizing planting, fertilizing, irrigation, and harvesting
  - Monitoring range health, soil erosion, soil recovery
  - Forest management: Monitoring forest health, deforestation, timber type, and planning harvests
  - Assessing fire hazards and monitoring forest fire

### 3.0 TROPICAL CYCLONE MISSIONS

UAVs have several features that allow them to complement existing weather research and monitoring capabilities:

- higher altitude than most manned aircraft, thus providing capability to fly above most violent weather
- longer endurance than most manned aircraft, thus providing capability for continuous monitoring
- the ability to move a sensor to a precise location at a selected time, in contrast to satellites or balloons
- longer dwell time in one location than satellites
- with appropriate sensors, the capability for *in situ* monitoring, from altitude to sea level in contrast to satellite observations.

Although routine weather reconnaissance could be done with UAVs, recent application studies indicate that the most valuable use is in challenging situations such as measurements of tropical cyclones. Four distinct missions have been identified and described by a science team commissioned by NASA's ERAST program (Elsberry, et. al., 1997). These are shown in Figure 3.

1. Track and landfall position forecasting
2. Intensity forecasting
3. Cyclogenesis
4. Landfall data gathering

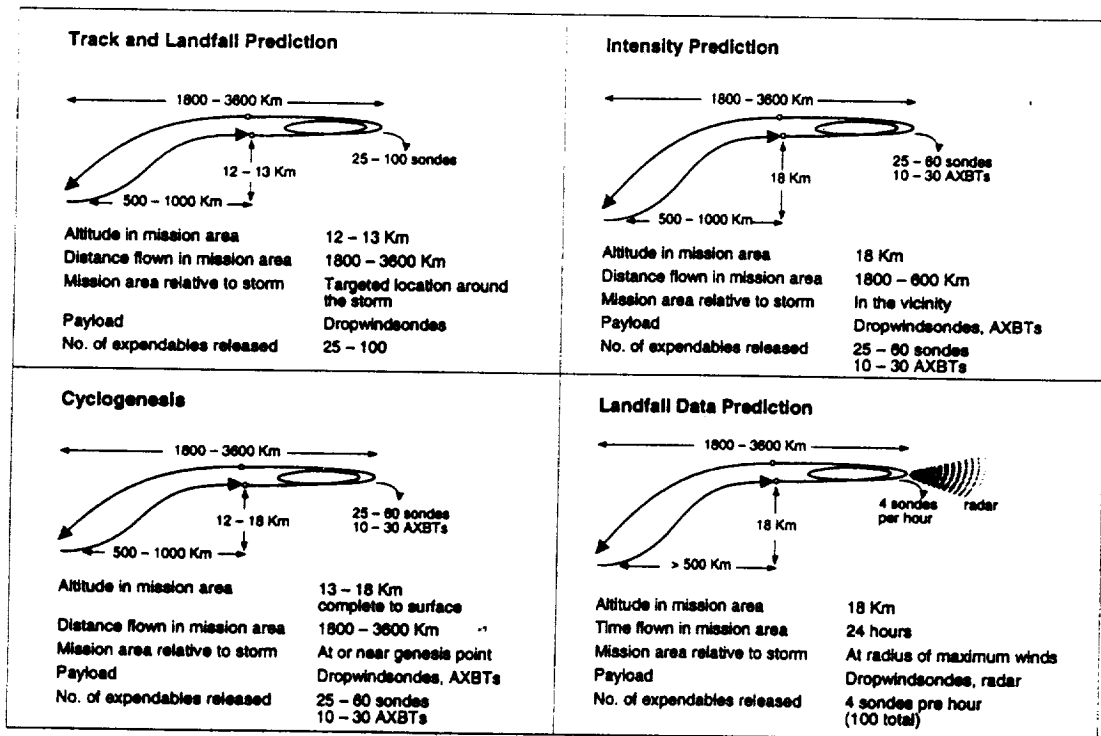


Figure 3. Four Tropical Cyclone Missions and Flight Requirements

The first two missions involve fully developed storms and the need for real-time *in situ* data as input to forecasting models. They differ, however, in that track forecasting require data at selected locations far

from the eye of the storm (Lorentz and Emanuel, 1998), whereas intensity forecasting requires data, especially temperatures, from sea surface to full height, at the center of the storm. Cyclogenesis is fundamental research, requiring data at the genesis point, usually far out at sea. Landfall damage models require data throughout the wind field as the cyclone reaches land and for some time after. These different missions all place different requirements on the monitoring aircraft, as shown in Figure 3. High altitude capability (above 17 km) is desirable in most cases, but some missions can be accomplished at 13 km, a recent conclusion based on observing systems simulation experiments (Zhang and Emanuel, 1999).

Figure 1 showed previously how a UAV would be used to gather meteorological data. Its payload would be GPS dropwindsondes and airborne expendable bathythermographs (AXBTs). Measurements include flight-level and vertical profiles of atmospheric temperature, barometric pressure, relative humidity, wind speed and direction from on-board meteorological sensors and the expendable sondes. A commercial satellite service, such as Orbcomm, Inmarsat, or Iridium, would be used for communications. Sensor data could be delivered in real time to meteorologists in their offices. Changes in flight plan or sonde deployment could be easily requested during a mission to adjust to changing conditions and maximize science return.

An aircraft with adequate payload capability could also carry a lightweight Doppler radar to measure wind fields at landfall. An aircraft that could loiter for 15 hours at a radius of 3700 km from its base would be able to collect data in most remote areas of the world while being based from established airfields.

#### 4.0 ERAST PLATFORMS

In an ongoing civilian program, NASA is proceeding to demonstrate how recent technological advances in UAVs can be used by the science community. The current ERAST program is funding demonstrations of several that have been developed specifically for remote sensing missions at 17 km and above. (Wagaman, et. al., 1998) These aircraft are the Perseus B, Altus DT, and solar Pathfinder (and its progeny). These are shown in Figure 4.

Perseus B, developed by Aurora Flight Sciences has achieved altitude of 60,000 ft (18 km). Endurance at altitude up to 6 hours is anticipated. Altus DT, developed by General Atomics-Aeronautical Systems, has flown over 57,000 ft (17 km). Both Perseus B and Altus DT use turbocharged propulsion technology, composite structures, and advanced command, control, and communications systems. Both can carry up to 100 kg. Both have been flight-tested in Southern California. Future demonstrations will extend operation of these aircraft to over-the-horizon flight capability through integration of commercial satellite communications capabilities.

Pathfinder, developed by AeroVironment, is a solar-powered aircraft that has flown over 80,000 ft (24.5 km) and has been used to acquire digital imagery. Current development of the Centurion and Helios solar-powered aircraft is aimed at higher altitude and longer flight duration, respectively. Performance of the ERAST aircraft is summarized in Table 1.

TABLE 1. ERAST Aircraft Characteristics

Aircraft	Altitude	Endurance at 15 km (50,000ft)	Payload	Propulsion
Perseus	20 km (65,000 ft)	10 hrs	100 kg	3-stage turbocharged
Altus DT	18 km (60,000 ft)	8 hrs	100 kg	2-stage turbocharged
Pathfinder	24.5 km (80,000 ft)	5 hrs	30 kg	electric / solar



Figure 4. Perseus B, Altus DT, and Pathfinder aircraft

## 5.0 SENSOR PAYLOADS AND SCIENCE MISSIONS

UAV science mission demonstrations are designed to collect data on natural and anthropogenic phenomena, leading to predictive models coupling elements of the global system. When flying science missions, the experimental design is driven by the science objective; this in turn determines the requirements for the sensor payload, airborne platform, and flight operations. In this section, several missions are described which are well suited to UAVs having the capability of the ERAST platforms.

**UAV ARM** ERAST is joining the Department of Energy's UAV Atmospheric Radiation Monitoring (ARM) mission. A top priority goal in the United States Global Change Research Program is improved understanding of atmospheric solar radiation and its interaction with clouds. The ARM program is conducting a flight series at the US Navy Pacific Missile Range Facility (PMRF) at Kauai, Hawaii, in early 1999. The primary instrument platform is the General Atomics Altus-DT. The purposes of this flight series are to investigate the optical and radiative properties of tropical cirrus clouds, measure geometric dependencies of flux measurements, and support satellite data retrievals.

The payload includes the following instruments: radiometers for zenith and nadir spectral measurements, reflected spectral radiance, downwelling hemispherical flux; upwelling hemispherical flux; broadband radiometer with hemispherical field of view; cloud detection lidar; and an *in situ* meteorological package to measure frost point, temperature, pressure at the aircraft's location.

**Pathfinder Hawaii** Two prototype UAV-class imaging systems have been developed under the ERAST program to demonstrate the utility of these new platforms to do remote sensing. These are the Digital Array Scanned Interferometer (DASI) and the Airborne Real Time Imaging System (ARTIS). Both

## 6.0 UAV DEVELOPMENT ISSUES

There are several subtleties that making UAVs valuable for gathering data, especially for meteorological and remote sensing applications. Development is still needed in these areas:

- Communications between the aircraft and its ground controller is critical. The ability to communicate over-the-horizon allows for remote applications. More experience is needed in this area.
- Current technology still requires nearly full-time oversight by a human controller. Enhancing adaptive autonomous capability will improve reliability and could ultimately reduce operating costs.
- The utility of a robotic aircraft can be increased if data collected during a mission can be monitored in real-time and used to make adjustments in the aircraft or payload operation during that mission. This has been demonstrated , but needs additional sophistication.
- Longer endurance at altitude is desirable for many missions. This will follow from propulsion system improvements.
- Regulatory policies and procedures need to be established for routine operation.

## 7.0 OPPORTUNITIES

The maturing of inexpensive UAVs with altitude capability of 17 km or higher will make possible remote sensing for many types of scientific, civilian and commercial applications. Imaging for mapping, disaster monitoring, and environmental purposes has been projected as large markets. It will be necessary to match sensor output with data analysis techniques and user facilities such as Geographic Information Systems (GIS). Integration of the sensor payload with the UAV platform is one issue. Business structures to meet these markets profitably must also be designed. Sensor systems are being developed for use in UAVs. UAVs are poised to make real contributions to earth science and commercial applications. NASA's ERAST program is developing and demonstrating capabilities to meet these markets.

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